[Proc. Roy. Soc. Victoria, 55 (N.S.), Pt. II., 1943.]

Art. X.—*Eocene Deposits South-east of Princetown, Victoria.*

BY GEORGE BAKER, M.Sc.

[Read 10th December, 1942; issued separately 1st October, 1943.]

Abstract.

Deposits of Eocene age are described from the Pebble Point district, south-east of Princetown, on the south coast of Western Victoria. The fossiliferous "Pebble Point Beds" have been established as of Eocene age from the evidence set out in the two following articles by Singleton and Teichert respectively. The Older Tertiary sediments overlying the Eocene Pebble Point Beds, are tentatively referred to the Eocene, pending the outcome of further fossil investigations. The relationship between the Jurassic rocks of this district and the Eocene rocks is described, and reference is made to Miocene beds appearing in coastal sections six miles north-west of the Eocene deposits.

Introduction.

This paper deals with the occurrence, nature, and stratigraphical relationships of Lower Tertiary deposits exposed in coastal cliff sections between Pebble Point and the mouth of the Gellibrand River, in the parish of Latrobe, counties of Heytesbury and Polwarth (fig. 1). The basal beds of the series, consisting of ferruginous sediments, called the Pebble Point Beds, are assigned an Eocene age from independent fossil determinations made by Dr. F. A. Singleton (10), of Melbourne University, and by Dr. C. Teichert (11), of the University of Western Australia, on material collected by the author in January, 1942. Beds of clay and sandstone overlying the Pebble Point Beds, are probably also of Eocene age, but this has not as yet been conclusively established.

Pebble Point, which has a N.-S. trend, is $2\frac{1}{2}$ miles south-east of the mouth of the Gellibrand River, and approximately $3\frac{1}{4}$ miles south-east of the township of Princetown, which is situated on the south coast of Western Victoria. It is made conspicuous among a number of small headlands having similar appearances by the presence of a marked storm-wave platform cut in the Eocene rocks about 25 feet above low-tide level. Adjacent headlands have wave-cut platforms in Jurassic rocks. Pebbles of jasper, flint, rhyolite, quartzite, and agate occur on the storm-wave platform at Pebble Point, and a prominent beach sand-ridge occurs in the bay immediately to the south-east. In the Pebble Point district, the Eocene deposits rest upon eroded Jurassic rocks (Pl. X., figs. 1 and 2) on the south-western flanks of the main Jurassic area in the Otway Ranges. They extend eastwards from Pebble

Point at heights in steep cliffs which are principally beyond reach, but in a north-westerly direction, the series dips gently at 5° seawards, so that from Pebble Point to within a quarter of a mile south-east of the mouth of the Gellibrand River, occasional access can be gained to several exposures of the Lower Tertiary deposits; many parts, however, are masked by cliff débris. The approximate thickness of the Lower Tertiary series between Pebble Point and the Gellibrand River mouth is given by Wilkinson (12) as 250 feet, and of this amount, the Pebble Point Beds of Eocene age total about 50 feet. Wilkinson's value was obtained by totalling the thicknesses of the strata at three different and relatively widely spaced cliff sections; a series of beds dipping at 5° and outcropping over a distance of some 2 miles, however, would have a total thickness of over 1,000 feet.

The general geology of the Princetown area is indicated on the accompanying map, which is based upon State parish plans in the southern portion of the counties of Heytesbury and Polwarth. Few surface exposures of the Jurassic rocks occur in the area embraced by the map, and then only in cliff faces and on wave-cut platforms at headlands. They are insufficiently extensive to appear on the map (fig. 1). Coastal exposures of the Tertiary rocks are

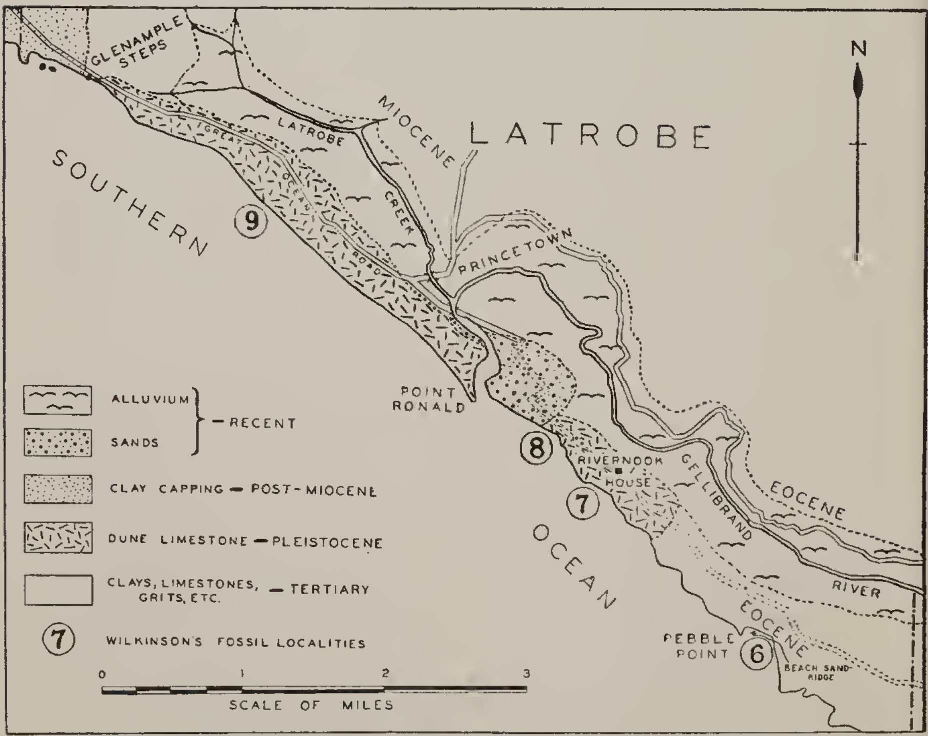


Fig. 1.—Geological map of coastline in the neighbourhood of Princetown.

principally absent from the plan, because of masking by covers of Recent sand dunes, Post-Miocene clays, and Pleistocene dune limestone.

Previous Work.

The difficulty of access to the area and the rugged character of this little frequented portion of the Victorian coastline, are probably the principal reasons why the Pebble Point Beds and overlying deposits have received little detailed attention in the field.

The deposits were first placed on record by Wilkinson in his survey of the Cape Otway country in 1865 (12). Fossils collected during this survey, marked as coming from No. 6 locality by Wilkinson (i.e. — the Pebble Point coastal section), were subsequently determined as Nautilus, Cytheraea, and Cucullaea, and the deposits were classed in the field by Wilkinson as Miocene (12). So far, the author has been unable to locate the repository of the fossil material brought back by Wilkinson from this locality. Wilkinson's results were re-stated by Duncan in 1870 (5), in his examination of the fossil corals from Wilkinson's No. 7 locality (see fig. 1), and again by Murray in 1877 (8).

In their catalogue of described fossil species from the Cainozoic rocks of south-eastern Australia in 1903, Dennant and Kitson listed two species of *Trochocyathus* (4), *Flabellum candeanum* Edwards and Haime (4, p. 132), *Natica hamiltonensis* T. Woods (4, p. 113), *Volutilithes antiscalaris* McCoy (4, p. 100), *Vaginella eligmostoma* Tate (4, p. 94), and *Panopaea orbita* Hutton (4, p. 126) from a locality "Rivernook." This locality is marked on the State parish plan of Wangerrip as a small township a short distance inland from the coastal sections in which the Eocene rocks are exposed. The above fossil names appear in Dennant and Kitson's lists in a group classed by them as of Eocene—Oligocene age, this group also containing suites of fossils typical of Balcombian rocks.

Duncan had previously described and illustrated the fossil corals collected by Wilkinson from No. 7 locality as *Trochocyathus victoriae* (5, Pl. XIX., fig. 3) and *Trochocyathus meridionalis* (5, Pl. XIX., fig 2), while a form with a thin corallum from the same beds was described as *Cycloseris tenuis* (5, p. 301, and Pl. XX., fig. 8), and it was stated by Duncan that thin species of the Cycloserides group of corals are found in the Nummulitic beds of Southern France (5). *Cycloseris tenuis* Duncan (7, p. 362) and *Trochocyathus meridionalis* Duncan (7, p. 431), have so far only been recorded from the Older Tertiary beds south-east of the mouth of the Gellibrand River. Species of Cycloseris are regarded as primitive forms of the genus Fungia, so that *Cycloseris tenuis* is

now classed as a sub-genus of Fungia, and becomes *Fungia* (*Cycloseris*) *tenuis* Duncan sp. Species of Cycloseris are most common in Upper Cretaceous and Eocene rocks (7, p. 486).

In 1904, Dennant described *Flabellum microscriptum* sp. nov. from Wilkinson's No. 7 locality, stating that it is apparently restricted to this locality and is accompanied by *Trochocyathus victoriae*, *T. wilkinsoni*, *T. meridionalis*, and a few species of mollusca, several of which are new and peculiar to the section (3, p. 53).

In the same year, deposits referred to by Chapman as "Black beds from east of the Gellibrand River" and from which shark's teeth were described, were classed as of Balcombian (Barwonian) age by Chapman (1, p. 277), i.e., as Oligocene according to the then current ideas of the age of the Victorian Tertiary deposits. The locality from which the shark's teeth were recorded, is given as A.W.7, i.e., Wilkinson's No. 7 fossil locality. The author has so far been unable to find shark's teeth in the "Black Beds" at this locality, but numerous examples occur in a sandstone band intercalated among the dark-coloured clay deposits at No. 7 locality. The forms identified by Chapman are *Odontaspis cuspidata* Agassiz sp. (1, p. 276), a form stated to occur in the Eocene and Miocene rocks of Europe and North America, and to have a time range from Upper Cretaceous to Miocene (1, p. 290). Another form, *Oxyrhina minuta* Agassiz (1, p. 283), is said to occur in the Oligocene of New Zealand. This was subsequently described as *Isurus minutus* Agassiz sp. by Chapman (2, p. 131), because of pre-occupation of the generic name Oxyrhina by another organism.

In 1923, Pritchard stated that the coarse grits with abundant broken and imperfect fossils east of the Gellibrand River, represented a shallow water phase of the lower horizon of the Janjukian (regarded then as of Eocene age by Pritchard), and that the predominating feature of the deposits was the mixed fauna of a strong littoral type (9, p. 935).

The Eocene age of the Pebble Point Beds (i.e., at Wilkinson's No. 6 locality), has been established by the contemporaneous recognition of the nautiloids *Aturoidea distans* Teichert sp. and *Nautilus victoriana* Teichert sp. (11) and the pelecypod Lahillia (10). It is noted that Aturoidea may even be of Upper Cretaceous age (11).

Mr. W. J. Parr and Dr. M. F. Glaessner have examined the matrix in which the Eocene mollusca were found, and also the clay beds overlying them, for foraminifera. No foraminifera were found in the clay beds, but the foraminiferal content of the Pebble Point Beds is listed in the accompanying appendix.

Occurrence, Nature, and Stratigraphical Relationships.

The bed from which the Eocene molluscs were collected is accessible in cliff sections at a point half a mile north-west of Pebble Point, at heights of some 40 to 50 feet above sea level, in a ferruginous series called the Pebble Point Beds, which are approximately 50 feet thick, and dip in a westerly direction. The contained fossils so far recognized are foraminifera, Aturoidea, Nautilus, Lahillia, Cucullaea, Nuculana, Limopsis, Eotrigonia, Dentalium, Natica, Turritella, a trochoid gasteropod, a small form of coral, large and minute fish teeth, claws of Callianassa, fish vertebrae, otoliths, whalebone fragments, and occasional fragments of fossil wood; the shelly fossils are often much broken and worn, and are embedded in a matrix of heavy grit with a ferruginous and argillaceous cement. The fossiliferous grit band overlies some 30 to 40 feet of shallow water, friable, sandy ironstones which form the base of the Eocene at this locality, and which so far have proved barren of determinable fossils, although rare, shell-like fragments can be detected.

The basal Eocene beds rest upon an erosion surface of arkoses (6) and occasional grits and mudstones of Jurassic age (Pl. X., figs. 1 and 2). Occasional grit bands, narrow veins and thicker bands of massive ironstone (limonite), occur in the Eocene sandy ironstones below the fossiliferous grit band, while narrow bands of copiapite-bearing clays and thicker bands of massive ironstone occur interstratified with the upper layers of the ferruginous beds.

Overlying the Pebble Point Beds occurs a deeper water sedimentary facies composed of dark-coloured, carbonaceous clays, which in parts contain abundant copiapite (basic iron sulphate) and structures resembling algal remains. The westerly dip of the series brings these clays down to sea level north-west of Pebble Point, and their thickness, as determined from a traverse along the coastal sections in the general direction of dip, is approximately 800 feet. Three bands of sandstone are interbedded in the carbonaceous clays, and are indicated in the coastal section (fig. 2). The nearest sandstone bed to Pebble Point, marked as "hard ferruginous sandstone" is partly ferruginous and possesses in parts rounded structures which have been produced by weathering. When broken open, some of these structures are found to be similar to "boxstones" in containing occasional casts and moulds of echinoids (Schizaster sp. indet.) and pelecypods, but the fossils are original to the deposit, and are not remanié as in true boxstones.

A second sandstone bed further to the north-west, contains numerous examples of a small form of Turritella, with corals, volutes, and Natica, while a short distance from this bed a third sandstone band 4-5 feet thick, contains abundant corals and shark's

teeth, and occasional specimens of Voluta and Dentalium. This bed is marked in fig. 2 as the "Trochocyathus-Odontaspis" band, and the locality corresponds to Wilkinson's No. 7 locality. Between, above, and below these bands of sandstone, the carbonaceous clays appear at intervals in the coastal sections, but in many places they are masked by recent talus cones built up by landslides and large fallen blocks of rock. In parts, the clays are pale yellow and grayish in colour from weathering, but when wet, the darker coloured portions are intensely black. Occasional polyzoal remains occur in clays above the Trochocyathus-Odontaspis bed, while cross sections of echinoid spines appear in a microscope section of pyritic portions of the clay from a locality about 1½ miles north-west of Pebble Point. Portions of the clay beds are distinctly shale-like and somewhat of a bituminous character, especially above the Trochocyathus-Odontaspis bed, where crystals of gypsum and abundant pale yellow, earthy copiapite are also prominent. This carbonaceous shale is overlain by 35 feet of unfossiliferous, friable, red and yellow ferruginous sandstones which show chemical banding and contain occasional hard bands of limonite. These beds are followed by 25 feet of dark-gray clay with structures and markings resembling algal remains. The outcrops in the cliff sections at this locality, correspond in position with Wilkinson's No. 8 locality, which is about half a mile south-east of the mouth of the Gellibrand River. The beds here dip at 5° in a direction a few degrees north of west. They are overlain by sandy clays and ironstone, 8 to 10 feet of black clay, followed by further sandy clays and ironstone, which all dip north of west at 4°.

The Older Tertiary beds at the north-west end of this traverse, cease abruptly against Pleistocene dune limestone deposits a quarter to half a mile south-east of the Gellibrand River mouth. From here to the Gellibrand River, the coastal district consists of Recent dune sands (fig. 1). Two and a half to three miles north-west of the Gellibrand River mouth, clays containing a typical Balcombian (= Miocene) fauna, appear in the coastal sections, at a position corresponding with Wilkinson's No. 9 locality (fig. 1). These beds dip westerly at 5°, but the dip values diminish in amount in a westerly direction; they are stratigraphically several hundred feet above the Pebble Point Beds.

There is a considerable gap in exposures of the Tertiary rocks in the central portion of the traverse line along the dip of the Tertiary beds in the Princetown district, because the Pliocene ancestor of the Gellibrand River had carved out a valley some 4 to 5 miles wide and over 300 feet deep in the Older Tertiary deposits. This valley was subsequently infilled in successive stages with Pleistocene dune limestone, through which the present Gellibrand River has cut its course. As a consequence, no exposures of Tertiary sediments are present for a half to three-quarters of

a mile between the Eocene beds south-east of the Gellibrand River, and the Miocene beds north-west of this river mouth. Difficulty of access to portions of the coastline north-west of the river mouth and the masking of the Tertiary rocks in most places by extensive talus cones containing large fallen blocks of Pleistocene dune limestone, are also partly responsible for the lack of detailed information concerning the beds intervening between Point Ronald and the Gellibrand Clays of Miocene age south-east of Glenample Steps (fig. 1).

The traverse along the coastal cliffs from Pebble Point to the mouth of the Gellibrand River, however, has yielded more favorable results, because the Older Tertiary rocks dipping in a general westerly direction, outcrop frequently over a distance of some 2 miles. The relationships of the various members of this series, as far as can at present be ascertained, are diagrammatically represented in fig. 2. East of the area embraced by the sketch geological section, the Eocene beds can be seen in parts at heights of 50 feet or more in high, steep cliffs, where they appear to be more or less horizontal; they have been traced out beyond Pebble Point, as far east as Moonlight Head. The Eocene also appears in road cuttings along the Great Ocean-road, on the northern side of the Gellibrand River, north-east of Rivernook House.

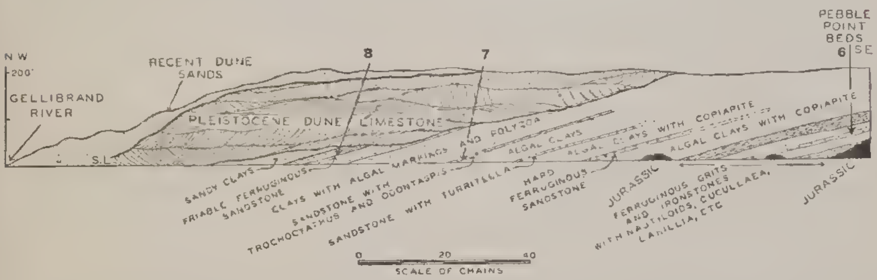


Fig. 2.—Geological sketch section along the coastal cliffs from the mouth of the Gellibrand River to Pebble Point. Dips of beds are exaggerated; the length of the section covers a distance of 2½ miles, and the maximum height of the cliffs is about 200 feet. Numbers above the section refer to Wilkinson's localities.

Eocene-Jurassic Relationships.

The unconformable junction between the basal beds of the Eocene and the eroded surface of the Jurassic sediments is sharply defined and relatively even in character in the cliff sections near Pebble Point. The surface of unconformity slopes down to sea-level ¾ mile north-west of Pebble Point, and becomes hidden by Recent beach sands, but a Jurassic outcrop of limited extent

appears in the coastal sections beneath Lower Tertiary clays, a short distance further to the north-west, thus indicating occasional undulations in the Jurassic sediments forming the floor of the Eocene sea. South-east of Pebble Point, the surface of unconformity rises to considerable heights in steep cliffs, and continues easterly for 4 miles to the Gable and Moonlight Head, in the parish of Wangerrip, where it has a more or less horizontal disposition.

The Eocene beds, which are conformable with one another, show slight amounts of transgressive overlap north-west of Pebble Point. Sandy ironstones, grit bands and narrow bands of massive ironstone (limonite) dipping westerly at 5° overstep one another on to the erosion surface in the Jurassic sediments, a surface which slopes at 10° in a westerly direction. On account of this overlap, it is reasonable to assume that still older members of the Eocene series may be hidden below sea level west and north-west of the Pebble Point Beds. Boring operations will be required, however, to establish this point.

On the seaward end of a wave-cut platform, which is 140 yards wide at the third point north-west of Pebble Point, massive blocks of Eocene ironstone, composed principally of limonite, rest upon the Jurassic sediments. Their disposition suggests that they have been lowered several feet on to the Jurassic platform, by the removal from below them of the more readily eroded Eocene sandy ironstones.

Occasional narrow cracks, an inch or so wide and 6 or 7 feet deep in the Jurassic rocks, have been infilled with material the same as that comprising the basal Eocene beds. Rounded pebbles of reef quartz are conspicuous in the matrix occupying these cracks.

Age and Thickness of the Tertiary Deposits.

Of the dipping Lower Tertiary beds exposed south-east of Princetown and extending beyond Pebble Point, only the Pebble Point Beds of grits and ironstones can at present be assigned an Eocene age with any degree of certainty. Approximately 50 feet of these deposits are exposed above the surface of unconformity with Jurassic sediments, but for reasons given earlier, this fossiliferous, ferruginous series of Older Tertiary beds may have a greater thickness than is evident at the surface.

The conclusion that the deposits are of Eocene age is based upon Teichert's (11) and Singleton's (10) fossil determinations in

the group of the mollusca, and is supported by evidence from the foraminiferal content (see appended list). The thickness of the sediments overlying Pebble Point Beds and terminating against dune limestone ½ mile south-east of the mouth of the Gellibrand River has been calculated graphically at about 1,000 feet. This value is obtained from the fact that beds dipping at 5° outcrop for some 2 miles; the effects of folding and faulting have been neglected from the calculation because there is no field evidence of such earth movements in the immediate locality.

Little conclusive evidence is at present available concerning the precise age of the deposits overlying the Pebble Point Beds north-west of Pebble Point In view of Duncan's description of the coral with a thin corallum. determined as *Cycloseris tenuis,* but now classed as *Fungia* (*Cycloseris*) *tenuis* (7, p. 362), and his record of abundant thin forms of the Cycloserides group in the Eocene sediments of Southern France, it is probable that the Tertiary deposits between the Pebble Point Beds and the Pleistocene dune limestone may also be of Eocene age. Other fossil forms like Odontaspis, Isurus, Trochocyathus, Turritella, and Schizaster, collected from the various members of this series, are types which elsewhere have a time range which includes the Eocene period, although they are not necessarily characteristic of that age, *Trochocyathus victoriae* Duncan sp., for instance, occuring Recent in Port Jackson and Port Stephens, New South Wales (7, p. 436), as well as in the Older Tertiary deposits above the Eocene beds of Pebble Point.

The fixation of the upper limit of these Eocene beds must, therefore, remain in abeyance until further evidence is forthcoming from investigations of the fossil content of the beds above the Pebble Point Eocene beds. From the field evidence, the author is inclined to the belief that all of the beds south-east of the mouth of the Gellibrand River are of Eocene age. This inclination is based upon the lithological and mineralogical similarities of those carbonaceous clays which are intercalated with the upper layers of the ferruginous Pebble Point Eocene beds, and those which occur at intervals up to 2 miles north-west of Pebble Point. There are also mineralogical similarities (see Table 1) between the Eocene grit bands and the three sandstone bands containing Schizaster, Turritella, and Trochocyathus-Odontaspis, respectively (fig. 2). In addition to this, there seems to be no doubt in the field that all of the beds south-east of Princetown are conformable with one another. The Turritella band also contains a few gasteropods comparable with ones in the Pebble Point Beds.

The changes in the lithological character of the sediments from south-east to north-west, indicate a deepening of the Lower Tertiary sea in a general east to west direction, the littoral facies of undoubted Eocene age at Pebble Point, giving way in the north-west to clays containing occasional interbedded sandstones. Three miles north-west of Point Ronald, clays of Miocene age, with a typical Balcombian faunal assemblage and with similar dips to the Eocene deposits some 6 miles to the south-east, pass upwards, with diminishing dips, into Miocene limestones, calcareous clays and marls. These are more or less horizontal in the vicinity of Glenample Steps (see map, fig. 1) and extend westerly for many miles through Port Campbell, Peterborough, and Warrnambool.

Post-Miocene clays and Recent sand dunes overlie the Miocene limestones, while Pleistocene dune limestones rest unconformably upon the eroded surfaces of many members of the Lower Tertiary strata.

Lithology and Mineralogy.

The mineral species represented in the various lithological types of the Lower Tertiary series south-east of Princetown, are listed in Table 1. Those from the Jurassic sediments of the immediate neighbourhood have been added for purposes of comparison.

Jurassic.

The Jurassic arkose near Pebble Point is calcareous (42 per cent. acid soluble), and contains a small amount (6 per cent.) of clay constituents. The sandy fraction of the arkose is composed principally of angular quartz, with some orthoclase and oligoclase, while there are also numerous sub-angular to rounded rock fragments of microscopic size, determined as andesite, muscovite schist, chlorite schist, sandstone, quartzite, mudstone, and hornfels (6) ; these rock fragments and the quartz grains are all of remarkably even grade size. Plates of fresh biotite, muscovite, green and reddish-brown hornblende, chlorite, colourless, pink and brown garnet, epidote, sphene, leucoxene, hematite, tremolite, zoisite, staurolite, and apatite, are also represented in addition to the minerals listed in Table 1. Thin sections of the arkose reveal abundant calcite acting as the cementing medium and forming rims to most of the small rock fragments and mineral grains. In this feature and in several other respects, the rock resembles some examples of the Jurassic arkose from the Gippsland bores, e.g., one from a depth of 1,163 feet in bore No. 4, at Boolarra.

TABLE 1.

		Rock.	Locality.	Calcareous Matter.	Rounded Quartz.	Angular Quartz.	Felspar.	Mica.	Glauconite.	Collophane.	Gypsum.	Iron Ores.	Limonite.	Pyrite.	Tourmaline.	Zircon.	Rutile.
Lower Tertiary.	1	Ferruginous Sandstone overlying 2	½ mile south-east of Point Ronald	−	+	(+)	+	+	−	−	−	+	+	−	+	+	+
	2	Carbonaceous Shale with Copiapite	½ mile south-east of Point Ronald	tr.	(+)	+	+	+	−	+	+	−	−	+	+	+	−
	3	Sandstone with Trochocyathus and Odontaspis	1 mile south-east of Point Ronald	+	+	(+)	+	+	+	+	−	+	+	+	−	+	+
	4	Sandstone with Turritella	1¼ miles south-east of Point Ronald	+	−	+	+	+	−	−	−	+	+	−	+	+	−
	5	Pyritic Clay ..	1½ miles south-east of Point Ronald	+	−	+	−	+	+	+	+	−	−	+	−	−	−
	6	Sandstone with "Boxstones"	1¾ miles south-east of Point Ronald	+	+	(+)	+	+	+	−	−	+	+	+	+	+	−
	7	Gritty Sandy Ironstone	¾ mile north-west of Pebble Point	+	(+)	+	+	+	+	+	−	+	+	+	+	+	−
Mesozoic.	8	Jurassic Calcareous Arkose	¾ mile north-west of Pebble Point	+	+	(+)	+	+	−	−	−	+	+	+	+	+	+

(+) Most common of types of quartz grains.

Lower Tertiary.

The sandy ironstone at the base of the Eocene series contains occasional fragments of angular quartz and felspar, and also reef quartz, Jurassic pebbles, and rare quartzite pebbles. In addition, rare rounded oolitic grains of the hydrated lime phosphate mineral collophane, pellets of glauconite and grains of black iron oxide, are set in a limonitic clayey base which forms the principal constituent of the rock.

Both the fossiliferous and the non-fossiliferous grit bands interbedded with the sandy ironstone, contain numerous large and rounded, translucent quartz grains, occasional gypsum crystals and quartzite fragments. These constituents are set in a clayey base which varies in composition from place to place. In parts, the base is ferruginous and phosphatic, and contains rare crystals of zircon, mica and tourmaline, pellets of collophane, and areas of glauconite sometimes associated with calcite. In other parts, the matrix is composed principally of calcite and limonite, while elsewhere, green and greenish-brown glauconitic mud is the most conspicuous constituent in the base of the rock. Smaller quartz grains in the grit bands are sub-angular to rounded and clear, the larger grains are frequently strained and granulated, and contain numerous strings of opaque, dust-like inclusions. Shell fragments are common in certain of the grit bands, and have in part been replaced by limonite and pyrite.

The carbonaceous clays overlying the basal ferruginous series contain pyrite in places. A section of pyritic clay, from $1\frac{1}{2}$ miles south-east of Point Ronald, revealed that quartz grains present were rimmed with calcite as in the calcareous Jurassic arkose. The pyrite, which is finely granular, sometimes forms rims to, or entirely replaces the oolitic collophane grains present, but principally replaces the argillaceous material forming the bulk of the rock. The section of pyritic clay also revealed rare cross sections of echinoid spines and occasional shell fragments. Carbonaceous shale from $\frac{1}{2}$ mile south-east of Point Ronald has certain characteristics akin to some oil shales. It has a sandy fraction of 7·5 per cent. and contains traces of calcareous matter. The sandy fraction is composed mainly of colourless, translucent, and milky grains of quartz. There are also flakes of mica up to 2 mm. across, and rare grains of heavy minerals (column 2, Table 1), while gypsum occurs as bladed crystals up to 3 mm. in length, and copiapite is abundantly developed along planes of fissility and as irregular clots. The cliffs here give off a sulphurous odour. A thin section of this shale indicated the presence of plant-like fragments.

Portions of the carbonaceous shale were tested for hydrocarbon compounds. After heating about 15 grams of powdered material

to a dull red heat in a hard glass test tube, abundant carbon was left behind in the residue. Volatile constituents from dry distillation consisted of water from which halite cubes crystallized on cooling, a small amount of sulphur, and a few drops of colourless liquid which had an aromatic smell and which when examined microscopically, were seen to contain pale yellowish-green globules of a liquid which persisted for several weeks. The halite cubes, which were accompanied by skeleton crystals of the same material, were probably derived from salt spray driven against the cliff face from the sea. Ten to fifteen grams of the shale were powdered and treated with absolute alcohol, and the argillaceous matter filtered off. The filtrate was allowed to evaporate slowly, and at the end of this process, brownish-yellow hydrocarbon residues having wax-like properties, remained as a thin film on the bottom of the containing vessel. A positive acetone test for hydrocarbons was obtained by shaking up about 10 grams of the powdered shale with acetone and filtering. The addition of water to the clear filtrate, resulted in a milky colouration due to the formation of an emulsion. This milkiness did not develop in a control test carried out by adding water to pure acetone. Twelve grams of the powdered shale were subjected to $5\frac{1}{2}$ hours' treatment with petroleum ether in a Soxhlet extraction apparatus. The residue obtained after evaporating the petroleum ether extract contained abundant small crystals of sulphur, a whitish, wax-like substance and a pale yellowish liquid with an aromatic odour. Owing to the small amounts of the residues obtained from each of the above tests, it has not been possible so far to arrive at any definite conclusion regarding the exact character of the hydrocarbon compounds present in the carbonaceous shale.

Of the interbedded sandstones in the clay series, the bed with structures resembling boxstones consists principally of quartz, with muscovite and some felspar set in a limonitic cement containing calcium carbonate and glauconitic material (column 6, Table 1, for rarer mineral species). The calcium carbonate forms rims around some of the sedimentary grains, and has also penetrated cleavage planes in certain of the mica plates. The sandstone band with Turritella contains some altered felspar and a carbonate cement in which angular to sub-angular quartz grains are set. The sandstone with Trochocyathus and Odontaspis has a ferruginous to calcareous cement, and contains a small proportion of oligoclase and mica. Nodular areas of pyrite up to 4 mm. across are numerous in this sandstone band, and frequently entirely replace the argillaceous matrix present in parts of the rock. Some of the angular to sub-angular quartz grains contain long, slender needles and minute prisms of apatite. Rare

glauconite and oolitic pellets of brown coloured material, probably collophane representing fish pellets, &c., are also present in this sandstone.

The ferruginous sandstone overlying the copiapite-bearing, carbonaceous shale about ½ mile south-east of Point Ronald, is friable and in parts micaceous, with angular to sub-angular quartz grains. Zircons occur both as clear, waterworn crystals and as examples with well preserved crystal faces like those in the Jurassic sediments. The other minerals present are listed in column 1, Table 1.

The minerals present in the Eocene sediments south-east of Princetown have several characteristics in common with the mineral assemblage of the Jurassic rocks upon which they rest. This is to be expected, as the basal Eocene beds are of terrigenous origin, their constituents being derived from a terrain composed of Jurassic arkose, grits, and mudstone. The pyrite in the argillaceous members of the Lower Tertiary series was probably formed by the action of H_2S evolved from decomposing organic material, with the aid of bacteria, on ferrous carbonate. Weathering of the pyritic matter has brought about conversion to basic ferric sulphate, resulting in the abundant development of the mineral copiapite in parts of the deposits. Hydrocarbon compounds present in the clays originate from plant material, represented by the dark carbonaceous markings resembling algal remains. The reef quartz pebbles in the Pebble Point Beds were derived from quartz veins which traverse the Jurassic sediments in parts of the Otways.

Summary and Conclusions.

A westerly dipping series of Lower Tertiary sediments composed of a basal ferruginous phase (called the Pebble Point Beds) overlain by a clay phase with interbedded sandstones, in coastal sections south-east of the township of Princetown, on the south coast of Western Victoria, have been assigned an Eocene age on their fossil content. They rest unconformably upon an eroded, somewhat undulating surface in Jurassic sediments, and show slight transgressive overlap. Balcombian (Miocene) beds in cliff sections some 5 or 6 miles north-west of Pebble Point, are separated from the older Tertiary sediments by a stretch of Pleistocene dune limestone which forms steep, rugged cliffs, at the base of which occasional outcrops of Tertiary rocks can be seen amongst large talus cones in those parts of the coast to which access can be gained. A considerable gap in certain parts of the Tertiary rocks between Pebble Point and Glenample Steps, has

been created by the eroded valley of the present Gellibrand River and its Pliocene ancestor, so that no definite conclusions can be made at present concerning the exact relationship between the Eocene and the Miocene deposits. The Eocene deposits have no other equivalents, as far as can be ascertained, along these parts of the Victorian coastline, being known so far only from the Pebble Point district.

Transgressive deepening of the Lower Tertiary sea from east to west is shown by the passage from basal Eocene grits and sandy ironstones, through clays and shales with interbedded sandstones, into Miocene limestones and calcareous, fossiliferous clays.

Evidence of Post-Miocene earth movements is provided by the elevation of the area of Eocene and Miocene sedimentation to its present position above sea level, but there was apparently no significant disturbance of the beds from their original disposition on deposition, the recorded dip values probably being initial dips controlled by the slope of the erosion surface of the Jurassic coastline, rather than dips resulting from tilting on elevation.

Instead of a continuous period of erosion leading to peneplanation throughout the Cretaceous and Eocene and into Oligocene times in Victoria, as originally appeared to be the case, it now transpires, with the determination of the Eocene age of the Older Tertiary deposits south-east of Princetown, that in portion of south-western Victoria at least, down-warping had set in towards the close of Cretaceous times. Erosion throughout the Cretaceous period had led to the development of a somewhat peneplaned area in the Princetown district. Increased amounts of down-warping led to the deposition of deeper water sediments in the west until, at the close of Miocene times, there was a reversal of movement, and the Eocene-Miocene rocks were elevated to form a land mass. The southern fringe of this elevated theatre of Older to Middle Tertiary sedimentation has been subjected to marine attack since Miocene times.

Acknowledgments.

The author wishes to express his appreciation of the work of Dr. C. Teichert and Dr. F. A. Singleton, whose fossil determinations have proved the presence of Eocene deposits in Victoria, at the locality described in the text. Thanks are also due to Associate Professor E. S. Hills and Dr. M. F. Glaessner for valuable help and advice, to Mr. W. J. Parr for his examinations of the foraminiferal content of the sediments from south-east of Princetown, and to Mr. J. S. Mann for photographic preparations.

Appendix.

The Foraminifera of the Eocene Beds at Pebble Point, Princetown.

By M. F. Glaessner, Ph.D., and W. J. Parr.

The presence of foraminifera in the Eocene beds of the Pebble Point area was first recognized by G. Baker, M.Sc., who subsequently asked us to examine some of the matrix adhering to the larger fossils to obtain, if possible, evidence from the microscopic fossils as to the age of the deposit. As no deposits now accepted as of undoubted Eocene age have hitherto been recorded from South-Eastern Australia, we were glad to comply with this request. In addition to the material with which Mr. Baker has supplied us, we have examined some better preserved material collected by one of us (W.J.P.) from the same beds in October, 1915.

Ferruginous grits, such as occur at Pebble Point, are as a rule, unfavourable to the occurrence and recovery of foraminifera in any numbers, and it is accordingly not surprising that in the present case the microfossils are rare and of small size. After a considerable amount of searching, we have found about 28 species of foraminifera and two of ostracoda. From the examination of the material, it is, however, apparent that much better preserved specimens could be obtained by careful collecting of samples from the less ferruginous portions of the deposit.

In the meantime, the following provisional list of species is placed on record:—

Dentalina sp.
Nodosaria sp.
Vaginulina sp. aff. *subplumoides* Parr.
Marginulina aff. *costata* (Batsch).
Marginulina aff. *glabra* d'Orbigny.
Lenticulina spp.
Planularia sp.
Lagena hexagona (Will.).
Lagena catenulata (Will.).
Lagena sp.
Globulina gibba d'Orbigny.
Guttulina problema (d'Orbigny).
Guttulina lactea (Walker and Jacob).
Guttulina sp. (adherent).
Angulogerina aff. *elongata* (Halkyard).
Eponides obtusus (Burrows & Holland) var. *westraliensis* Parr.
Gyroidina aff. *octocamerata* Cushman & Hanna.
Pulvinulinella sp. nov.
Baggatella sp. nov.
Ceratobulimina spp. nov.
Anomalina sp. nov.
Anomalina cf. *glabrata* Cushman.
Cibicides cf. *lobatulus* (Walker and Jacob).
Cibicides spp.
Globigerina sp.

Echinoid spines, bryozoan fragments, small mollusca, ostracods and fish teeth occur also in the washings.

All foraminifera are rare except *Anomalina* sp. nov. and *Cibicides* sp., which were found in considerable numbers.

From this list, we have drawn the following conclusions:—

1. The assemblage is unlike any other hitherto recorded or known to us from Australia. The most characteristic species of the deposit appear to be new. A number of other species have a long range in time.

2. There is no disagreement between the composition of the fauna and the determination of the Eocene age of the beds at Pebble Point as based on distinctive species of mollusca.

3. Our present knowledge of the foraminiferal assemblage of the ferruginous grits from Pebble Point is insufficient for an independent determination of their age. At least four out of a total of about 28 species appear to be closely related to species not known from Tertiary deposits younger than Eocene. One of these species belongs to the genus *Baggatella* which was described recently by H. V. Howe from the Middle Eocene of Texas, U.S.A. (see Louisiana Geol. Survey, Bull. 14, p. 79). The number of specimens at present available does not enable us to reach a more definite conclusion.

4. The composition of the fauna indicates deposition in shallow and rather cool water. This opinion is based on similarities with fossil foraminiferal assemblages from sediments known to have been formed under such conditions.

References.

1. Chapman, F.—Fossil Fish Remains from the Tertiaries of Australia. *Proc. Roy. Soc. Vic.*, xvii. (i), n.s., pp. 267-296, 1904.

2. ————, Some Cainozoic Fish Remains, with a Revision of the Group. *Ibid.*, xxxvi. (2), n.s., pp. 107-162, 1924.

3. Dennant, J.—Descriptions of New Species of Corals from the Australian Tertiaries. *Trans. and Proc. Roy. Soc. Sth. Aust.*, xxviii., pp. 52-76, 1904.

4. Dennant, J., and Kitson, A. E.—Catalogue of the Described Species of Fossils (Except Bryozoa and Foraminifera) in the Cainozoic Fauna of Victoria, South Australia, and Tasmania). *Rec. Geol. Surv. Vic.*, Vol. I., Part 2, pp. 89-147, 1903.

5. Duncan, P. M.—On the Fossil Corals (Madreporaria) of the Australian Tertiary Deposits. *Quart. Journ. Geol. Soc.*, xxvi., pp. 284-318, 1870.

6. Edwards, A. B., and Baker, G.—Jurassic Arkose in Southern Victoria. *Proc. Roy. Soc. Vic.*, lv. (2), n.s., 1943.

7. Felix, J.—Fossilium Catalogus. *Anthozoa Miocaenica* (1), 35, 1927.

8. Murray, R. A. F.—Report on the Geology of Portion of the Cape Otway District. *Geol. Surv. Vic. Progress Report*, Vol. IV., pp. 127-133, 1877.

8. Pritchard, G. B.—The Character and Sequence of the Victorian Tertiaries. *Proc. Pan. Sci. Congress (Australia)*, Vol. 1, pp. 934-939, 1923.

10. Singleton, F. A.—An Eocene Molluscan Fauna from Victoria. This volume, pp. 268-281.

11. Teichert, C.—Eocene Nautiloids from Victoria. This volume, pp. 257-265.

12. Wilkinson, C. S.—Report on the Cape Otway Country. *Geol. Surv. Vic.* Report for 1863-1864, pp. 21-28, 1865.

Explanation of Plate.

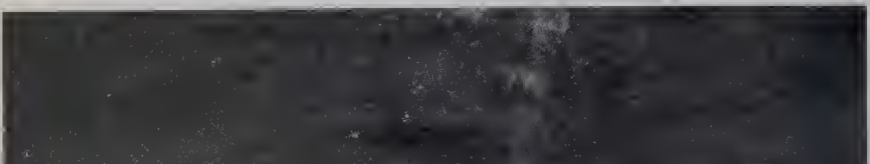
PLATE X.

FIG. 1.—Lower portion of the cliffs at the second point north-west of Pebble Point, showing Jurassic beds on the wave-cut platform and in the base of the cliffs. Overlying them are westerly dipping Eocene beds.

FIG. 2.—Close-up of the unconformity between Eocene and Jurassic sediments at the second point north-west of Pebble Point, showing the even character of the old erosion surface at this locality.

(NOTE.—The dotted line in each photograph marks the surface of unconformity between Eocene and Jurassic rocks.)

1



2

[Page 255.]

3130/43.